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The (Present) Age of Quantum Computing

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Mini Review

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Abstract

Quantum computing is an intense and challenging research area, that promises to change the world we live in. But what is its current status, both in terms of understanding and applications? We discuss some points related to this question in this article.

Keywords: Quantum computing; Quantum theory; Technology; Applications

Mini Review

Quantum Theory (QT) provides a very special case of scientific development in the history of science. Since its inception, in the second decade of the last century, it has been applied in the understanding and prediction of several natural phenomena. Its predictions and theoretical framework have passed all the tests ever performed, which makes it possible to say that it is the most successful scientific theory in human history.

Its development enabled the emergence of numerous technologies, and without it, what we know today as the information age would not exist. Its impact on society is immeasurable and without its advent, humanity would live in a completely different world.

However, since its inception, QT has been the object of intense debate and philosophical controversies about its foundations and interpretations [1]. The most fundamental physical meaning of quantum phenomena and how they build the reality we observe are objects of struggle until the present day. This context becomes clear when one realizes the importance and intense activity in the area of research in Physics known as "Foundations of Quantum Theory" [2]. Advances in this area generate theoretical and practical impacts, both in our understanding of the world and in the way we develop new technologies [3].

In 1981, the renowned physicist Richard Feynman (1965 Nobel Prize in Physics) proposed the use of (intrinsically) quantum phenomena to build a new type of computer, with a capacity superior to existing computers (at that time and still today) [4]. Thus, the idea of a quantum computer arises from there: a new computational model, based on principles of QT, which in principle would be able to solve intractable problems for "classical" computers.

Classical computing is based on bits (binary digits), its smallest unit of information, which can assume one of two possible values (states) at a time, commonly denoted by 0 and 1. In quantum computing (QC), the smallest unit of information is the "quantum bit" (or qubit), which can assume both classical values at the same time, due to the quantum phenomenon of superposition. Due to this fact, a quantum computer could store and transmit much more information than a classical computer. For example: for a number N of classical bits in one of the two possible states, we would have 2^N possible quantum states [5,6]. In other words, N qubits could store the information of 2^N classical bits. Another characteristic of qubits is that they can be in an entangled state [7]. Given two or more qubits, the total state of the system as a whole can be constituted in such a way that the individual identity of each qubit is lost, and information can only be obtained about the complete system. These entangled states are purely quantum, and have no classical description. They can be used for transmission of typically quantum information, and are the basis of the protocol known as "quantum teleportation" [8].

The physical realization of quantum computers, in turn, constitutes a major technological challenge. Only a few years ago this was realized, but only in a few technology centers and universities. That is, there is still no concrete prospect that quantum computers with good storage and processing capacity will be widely disseminated and commercially viable. Several aspects need to be better understood and controlled for this, from the theoretical, hardware and software (programming) points of view.

Regarding the first aspect, a better understanding of the foundations of QT is essential. Several phenomena are still predicted and discovered at daily basis and some of these with direct possibility of application in the implementation of quantum computers.

In the development of physical machines, that is, hardware, great obstacles must be overcome. Quantum systems, when interacting with the environment in which they are immersed, lose their quantum characteristics. This fact is related to what we call the measurement problem and the phenomenon of decoherence [9]. By losing these features, the advantages of storage and speed of transmission of information characteristic of quantum computers are also lost. In this way, the control of the environment and its interaction with quantum systems is essential and, on the other hand, very difficult to be established. Vacuum chambers, very low temperatures and insulation are some of the needs, which also highlights the reason why there is still no prospect of commercializing these computers [10,11].

Software development is an active area of research, which presents itself as an intersection between Physics, Computer Science and Mathematics [12]. New algorithms, based on the logic of QT, are needed to explore the full capacity of quantum systems and some of these are already part of the literature on the subject [5,6,12]. Also, some frameworks and software development kits have already been developed and made available for public use [13].

All this new reality will certainly change the way and the emphasis with which QT and QC are taught [14,15]. The world's first portable quantum computer [16], which is capable of processing two qubits and is based on the use of nuclear magnetic resonance, has been used to education in QC and some simple scientific research.

Faced with these challenges, the perspectives, in turn, are encouraging. Some possibilities of applications of QC in the study and understanding of the human brain have already been considered [17,18], as well as its use in some areas of medicine [19,20]. Finance [21], ecology [22], electronic security [23] and military applications [24] are some other areas where QC is already being integrated, in connection with artificial intelligence, machine learning and data science [25].

A study of 2018 shows that, among emerging technologies, there is a "hype" related to QC, considered as an innovation, and that this technology should be established until 5 to 10 years, that is, between 2023 and 2028 [26]. Besides that, there is a prediction that 20% of technology companies should have sectors dedicated to QC from 2023 [21]. Daily news about QT applications in technology can be followed at Inside Quantum Technology News [27].

Concluding Remarks

It can be seen that the current state of QC and its consequences for a deeper understanding of nature, as well as futures applications, is one of intense research and development [28]. Several initiatives in favor of quantum computing and quantum technology are already being carried out around the world, both by governments and the private sector, and the prospect of funding is ever increasing [29].

It is reasonable to believe that this situation will be intensified in the coming years. Therefore, new forms of teaching and insertion of QC in schools and basic research institutions also become increasingly important areas of research and academic collaboration.

Given its fundamental role in deepening our comprehension of the world, its possible interface with other areas of knowledge and its potential to generate new technologies, it becomes difficult not to imagine a very near future in which QC and its ramifications will be present in our everyday life.

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